Brazing filler materials

For *efficient, strong and defect free* brazing, the filler material should have following properties:

- Filler material should have ***ability to form braze joint***
- Physical ***(electrical, CTE etc)*** ,
- Mechanical ***(ductility, toughness etc)*** and
- Chemical properties ***(avoidance of atmospheric or galvanic corrosion etc).***

Requirements

Temperature should be in the range to give ***proper flow*** for capillary action ***(lower than the solidus of base metal and higher than the liquidus of filler metal).*** Composition should be sufficiently homogeneous and stable to ***avoid liquation***.

Composition must be chemically compatible to ***avoid sacrificial corrosion.***

For sound joint the filler metal should have ***sufficient wettability***.

Other than diffusion brazing, ***inter diffusion*** of the constituents of base metal and filler metal should be ***avoided***.

Composition different from filler metal can have different melting temperature. This can also cause ***formation of brittle structures.***

Braze filler selection criteria

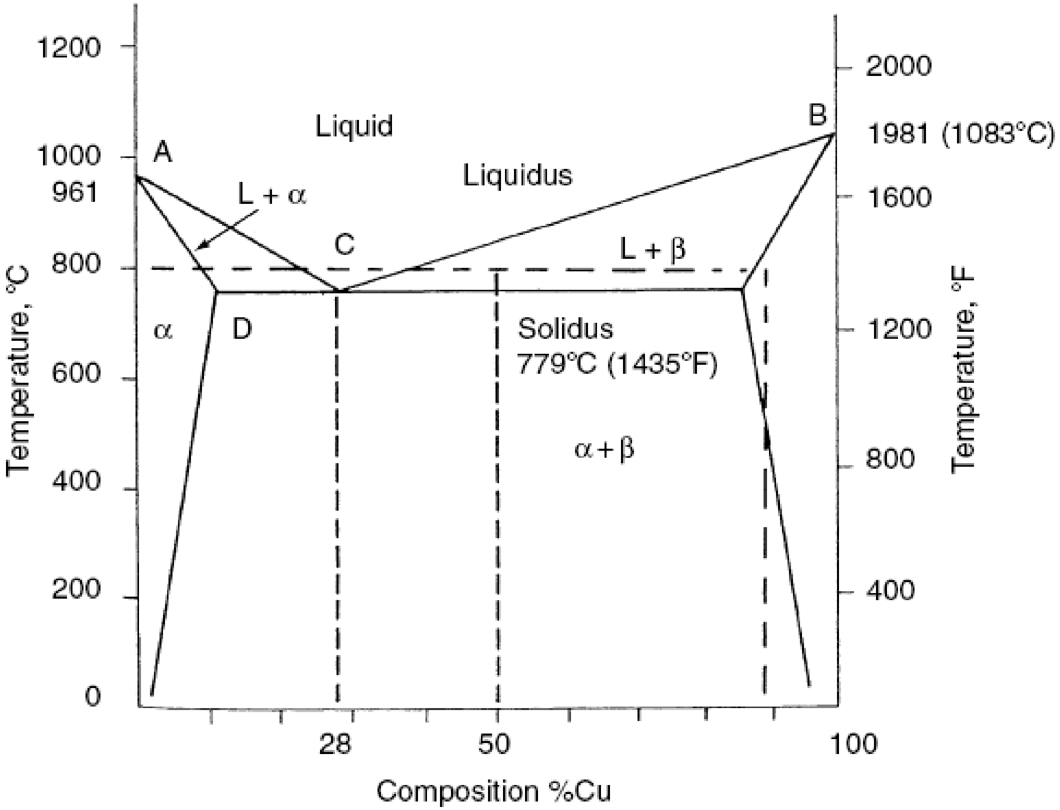
Compatible with ***physical, mechanical and chemical*** properties of the base metal and joint design.

Compatible with service environment.

Low temperature braze filler are preferred for ***economizing*** and ***minimizing*** **heat effects** while high temperature filler are used for ***high MP materials*** to get good strength.

Normally alloys are used with ***narrow melting range (30-50 °C).***

Filler with ***wider*** melting ranges are prone to ***liquation.***



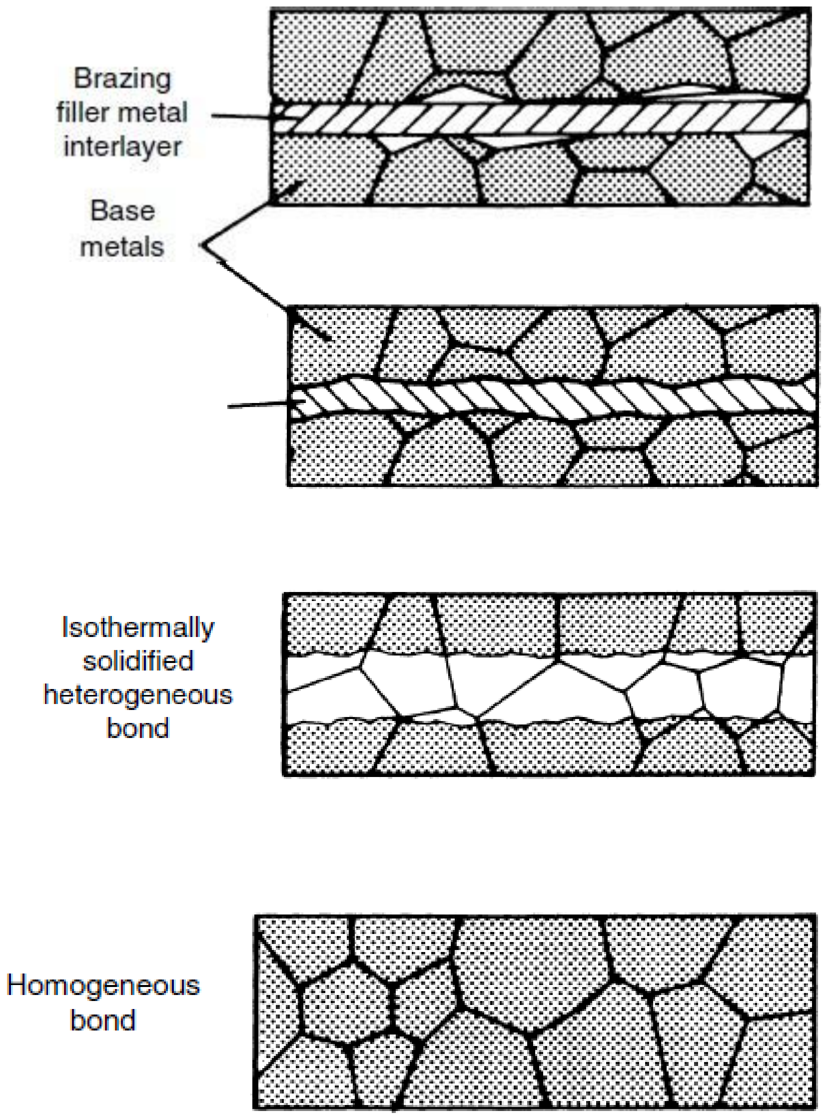
Diffusion brazing

Joint is formed by holding the brazement at certain temperature for sufficient time rather than the filler melting and flowing as in normal brazing.

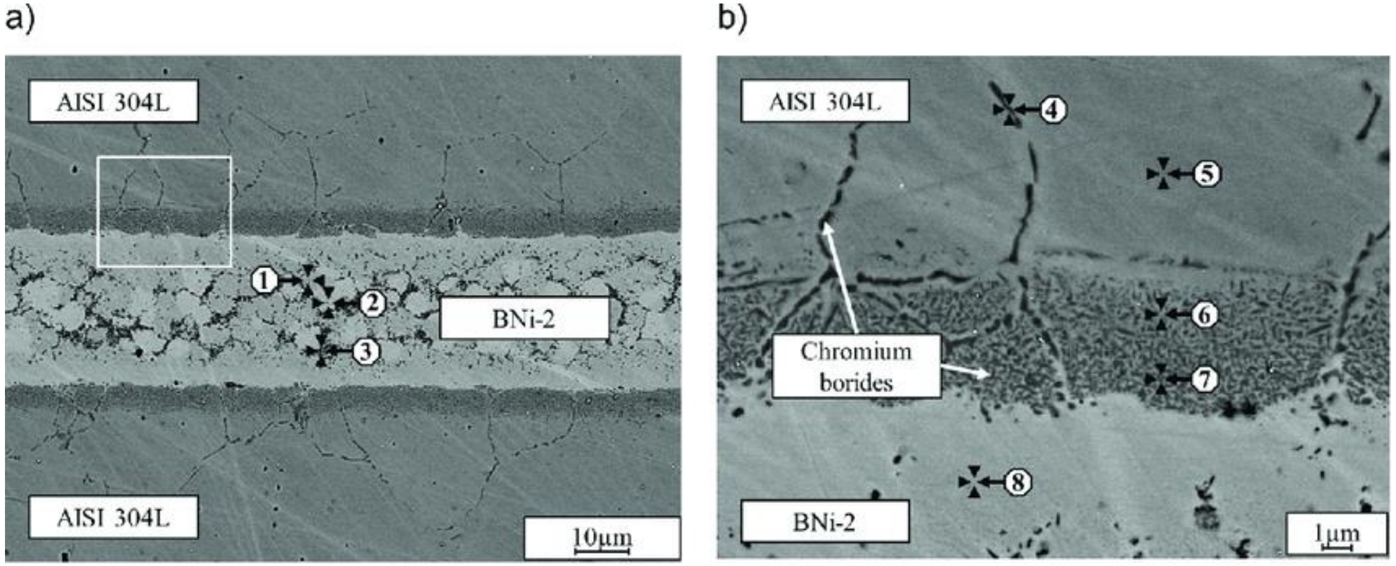
There is no well defined interface in diffusion brazing due to inter diffusion of elements from base metal and filler.

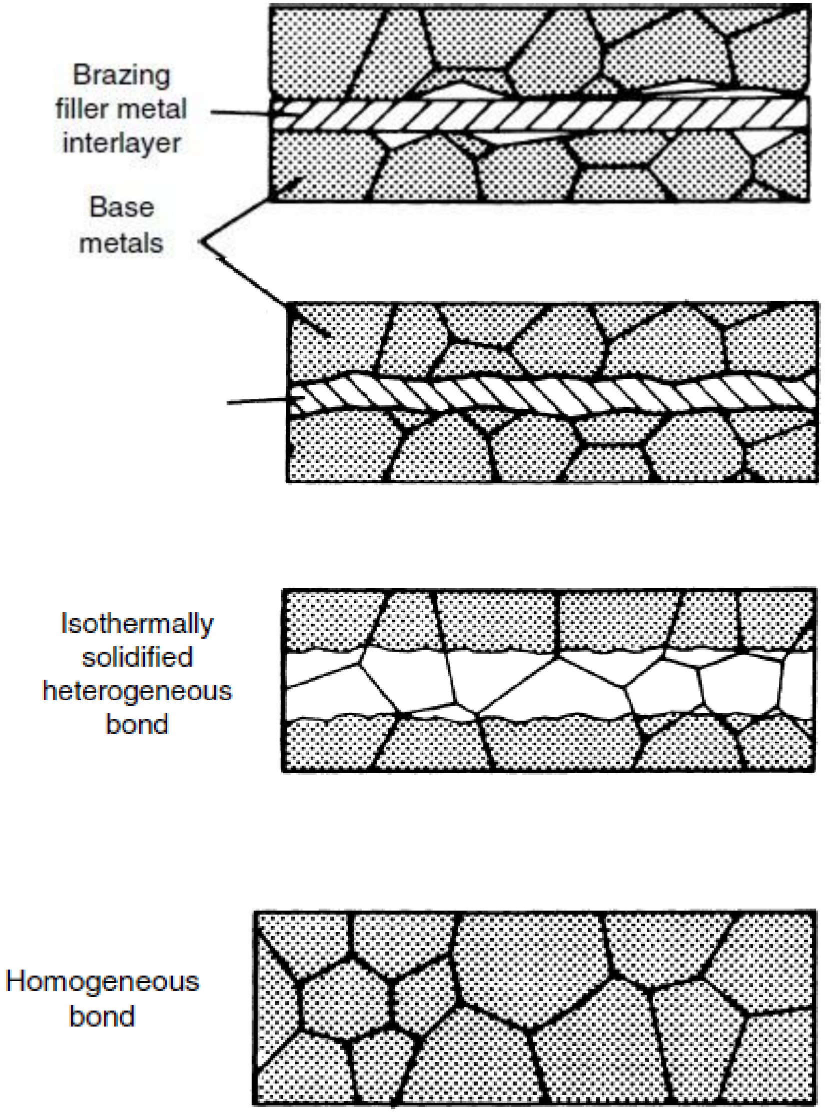
Isothermal solidification is started from the changed composition near to the faying surfaces as inter-diffusion change the original eutectic composition of the filler.

Joint produced from diffusion brazing is stronger than normal brazing process



Diffusion brazing





Soldering

A ***sub brazing*** process in which coalescence is produced by filler metal having ***liquidus temperature below 450°C***. Like brazing filler metal is distributed in cavity by ***capillary action*** and ***fluidity***.

The joint formed in soldering is combination of ***mechanical*** and ***chemical bonding (metallic).*** Solder don't dissolve in base metal, it remain as distinct interface between joint.

Solderability of a material

- *Ease of spreading*,
- *Solvent action*
- *Wetting*

Materials Joined

- *Metal and alloys*
- *Intermetallics*
- *Ceramics* and *glasses*
- *Combination*

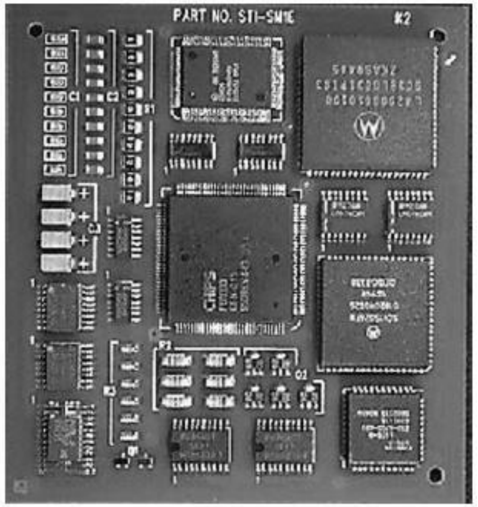
Attributes

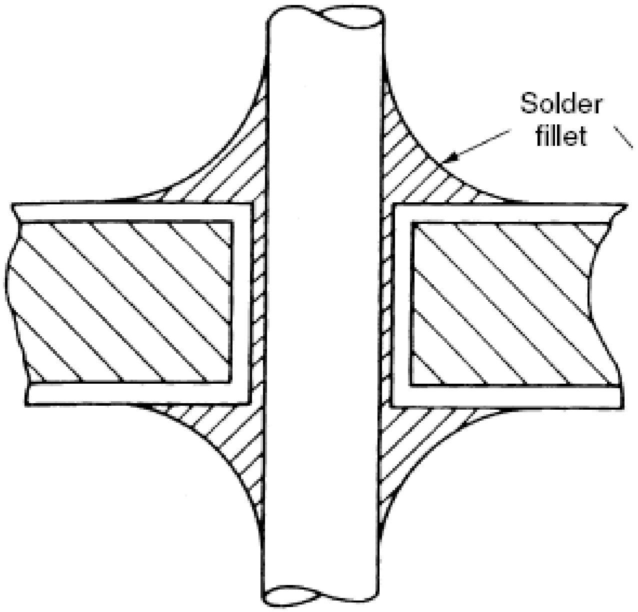
- *Partial dissolution,*
- *Compound formation*
- *Metallic bonding*

Soldering

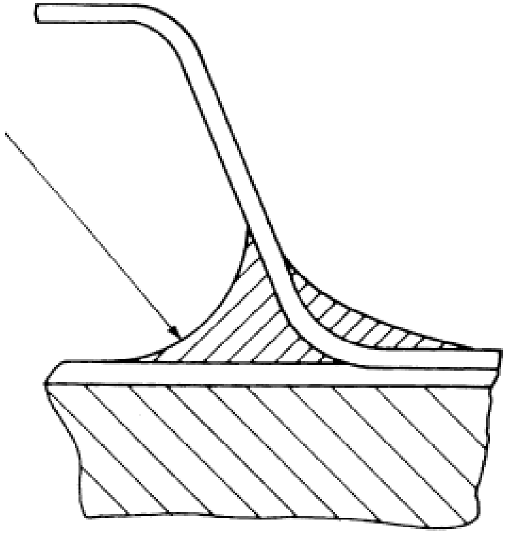
Applications

- ***Electrical connections***
- **Sealing** *(leak tight joints)*





Through-hole lead



Surface-mount

- **Jewelery**
- **Cu/Al tubing**
- **Cans**
- **Electronic circuits**

Advantages and Disadvantages

Advantages	disadvantages
Joint formation is self controlling	Limited strength
Many joints can be produced at once	Low service temperature
Localized heat is not necessary	Uniform heating is detrimental in some cases
No composition or microstructure change	Production of multiple joint make inspection more difficult
Considerable freedom in joint dimensioning	
Process can be automated	
Allow disassembly or de-soldering	Cyclic heating can change the microstructure

Soldering process consideration

- Base material selection
- Solder selection
- Flux selection
- Joint design
- Joint pre cleaning
- Soldering process selection
- Flux or residue removal
- Joint inspection

Solder characteristics

Solder should have melting temperature lower then 450°C

- *Good fluidity,*
- *Wetting,*
- *Reasonable strength,*
- *Electrical conductivity*
- *Thermal conductivity*

(eutectic mixtures of low melting point metals)

Fluidity of solder other then eutectic mixture depends on liquid-solid content at soldering temperature.

Major alloy systems used for solders include; *lead-tin, tin-antimony, tin-antimony-lead, tin-silver, tin-silver-lead, tin-zinc, cadmium-silver, cadmium-zinc, zinc-aluminum, bismuth and indium alloys.*

Due to ***toxic*** and atmospheric ***pollutant*** nature of lead, it is generally advisable to use ***lead free solders***

Metallurgy of lead tin solder

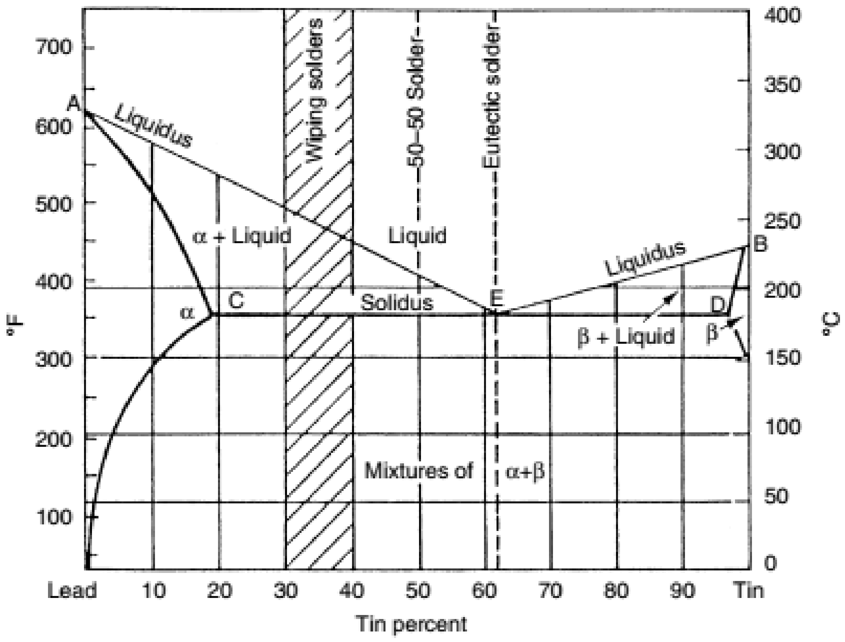


Figure 8.7 Phase diagram for the Sn–Pb binary alloy system. (Reprinted from *Sol Manual,* 2nd edition, Fig. 2.1, page 5, American Welding Society, Miami, FL, 1978 permission.)

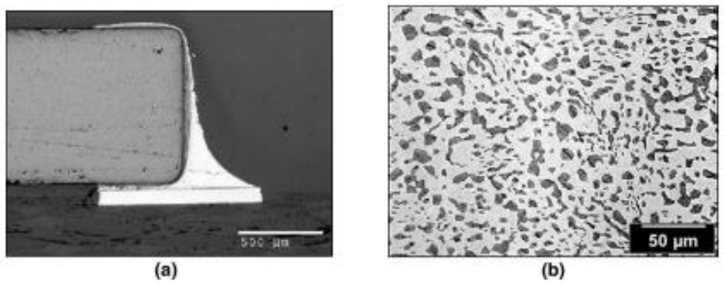
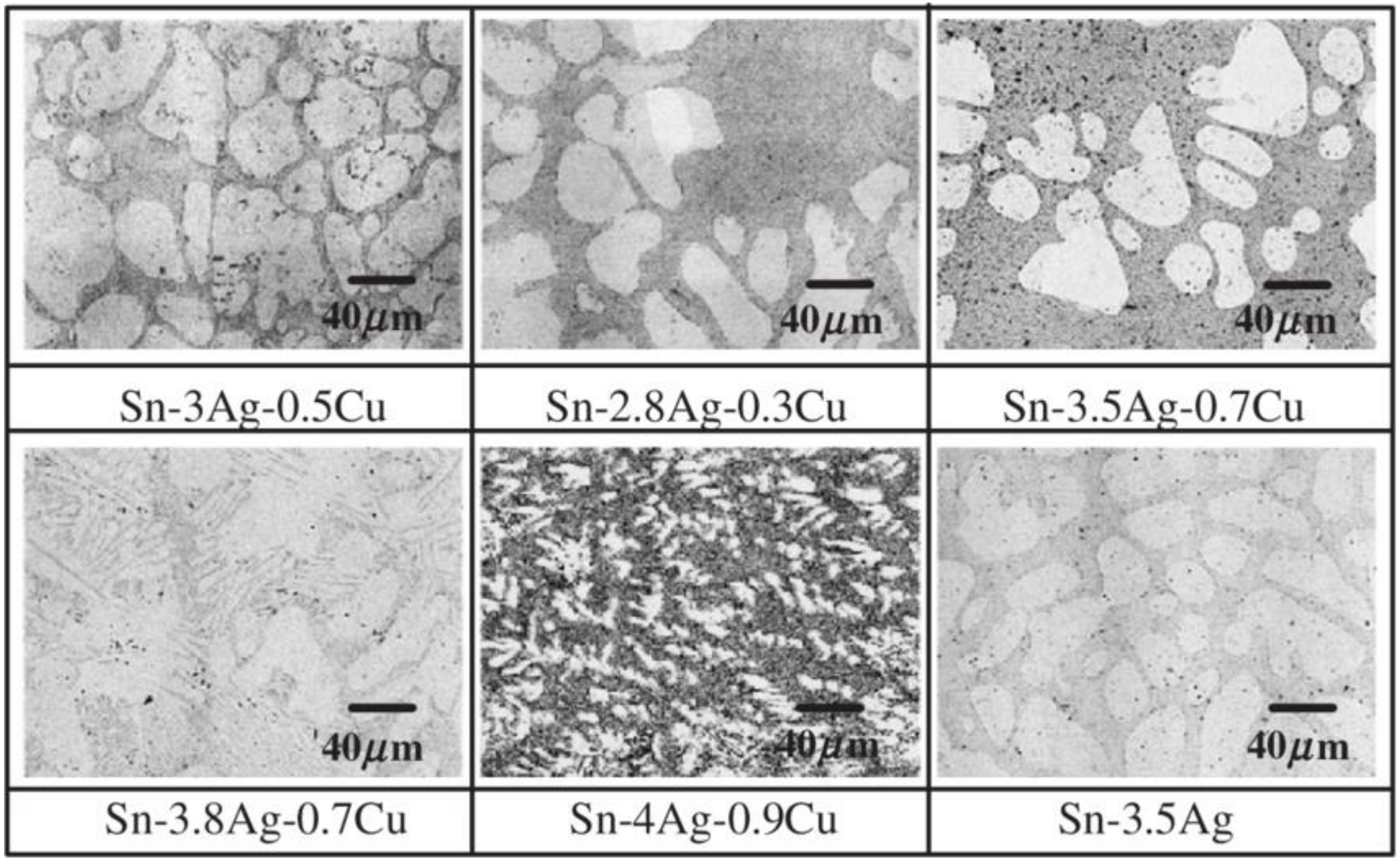


Figure 8.8 A photomacrograph (a) and photomicrograph (b) of a typical near-eutectic 60Sn–40Pb solder showing the self-formation of smooth fillets due to wetting action (a) and the eutectic constituent made up of lamella of the Sn-rich and Pb-rich solid solution phases (b) (Courtesy of Sandia National Laboratories, Albuquerque, NM, with permission.)

- 5–95 is relatively high melting, has a narrow melting and freezing range, and is poor in terms of wetting and flow compared to higher Sn alloys. Mechanical properties of this high-Pb alloy are better at 149°C (300°F) than most other alloys with more Sn.
- The 10–90, 15–85, and 20–80 solders have progressively lower liquidus and solidus temperatures, a wider melting range, and better flow than 5–95. All are prone to solidification cracking or "hot tearing," however, if movement occurs during cooling (e.g., from thermal contraction stresses).
- The 25–75 and 30–70 solders have lower liquidus temperatures than all previous, more Pb-rich solders, but the same as 20–80. The melting range is thus narrower, so there is a lesser tendency toward hot tearing.
- The 35–65, 40–60, and 50–50 solders have low liquidus temperatures and, as a group, have the best combination of wetting, strength, and economy.
- The 60–40 solder is used whenever exposure temperature restrictions are critical for the assembly or some of its components, since the composition is close to the eutectic. It is cheaper because it contains slightly less expensive Sn than the true eutectic at 63–37.
- The 70–30 alloy is a special-purpose solder used where a high Sn content is required for wetting or other compatibility.

Metallurgy of lead-free solder



Solder Alloys

Tin-lead solders

- Commonly used for soldering all metals/alloys
- Good corrosion resistance
- Different compositions along with different fluxes can be used according to material

Tin-antimony and tin-lead-antimony solder

- Stronger then tin-lead solders
- Good creep strength
- Use in *plumbing, refrigeration and air conditioning* work.
- *Antimony is toxic as lead so avoided in food and beverage processing etc*

Tin-silver and tin-lead-silver solder

- Used for stainless steel and food processing applications.
- Addition of Ag in lead-tin gives high *temperature tensile, shear, creep and toughness*

Cadmium-silver solders

- Joint strength is very high when joining copper
- Cadmium is toxic, so care should be taken during process and subsequent disposal

Zn-Aluminum solders

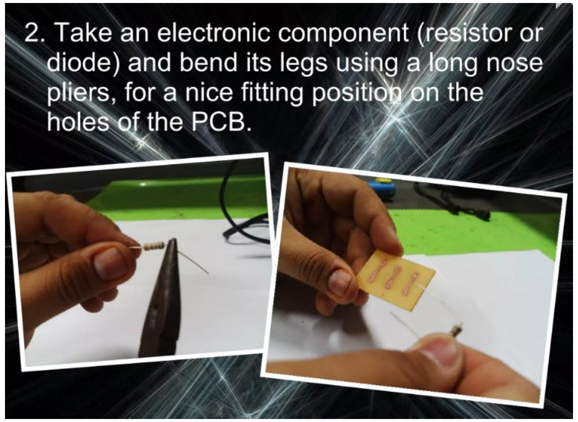
Used for Al-alloys, gives high strength and corrosion resistance

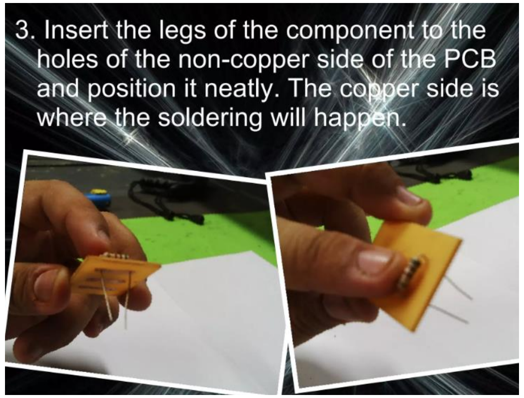
Lead-free Solders Preferred by Industry

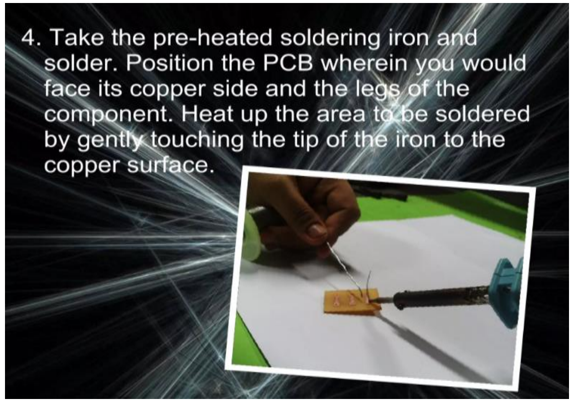
Solder	Melting Range (°C)	Industry Served
SnCu	227	Consumer, Telecommunications
SnAgCuSb	216-222	
SnAg	221-226	Automotive
SnAgBi	206-213	Military, Aerospace, Consumer
SnAgBiCu		Military, Aerospace
SnAgBiX	206-213	Consumer
SnAgCu	217	Automotive, Telecommunications
SnZn	198.5	Consumer, Telecommunications
SnBi	138	Consumer

Physical Forms of Solders

Pig	Available in 25 and 45 kg (50 and 100 lb) pigs
Ingots	Rectangular or round; 1–4, 2–3, and 4–3 kg (3, 5, and 10 lb)
Bars	Available in many cross-sections, weights, and lengths
Paste or cream	Available as mixture of powdered solder and flux
Foil sheet or ribbon	Available in various thicknesses and widths
Segment or drop	Triangular bar or wire cut into any number of desired pieces or lengths
Wire, solid	Diameters of 0.25 to 6.36 mm (0.010 to 0.250 in.); spools
Wire, flux-cored	Solder covered with rosin, organic, or inorganic fluxes; diameters as above
Preforms	Unlimited range of sizes and shapes to meet need







SOLDERING IRON

SOLDER

Welding Defects

A weld defect results from a poor weld, weakening the joint. It is defined as the point beyond the acceptable tolerance in the welding process.

Weld irregularities occur for a variety of reasons, and it results in different welding defects. They can be classified into two major categories:

Internal welding defects and

External welding defects.

Cracks

Cracks are the worst welding defect since they can rapidly progress to larger ones, which inevitably leads to failure. Weld cracks are mainly classified depending on how they form in the weld bead.

Longitudinal cracks form parallel to the weld bead while **transverse cracks** form across the width. **Crater cracks** form at the end of the bead, where the arc concludes.

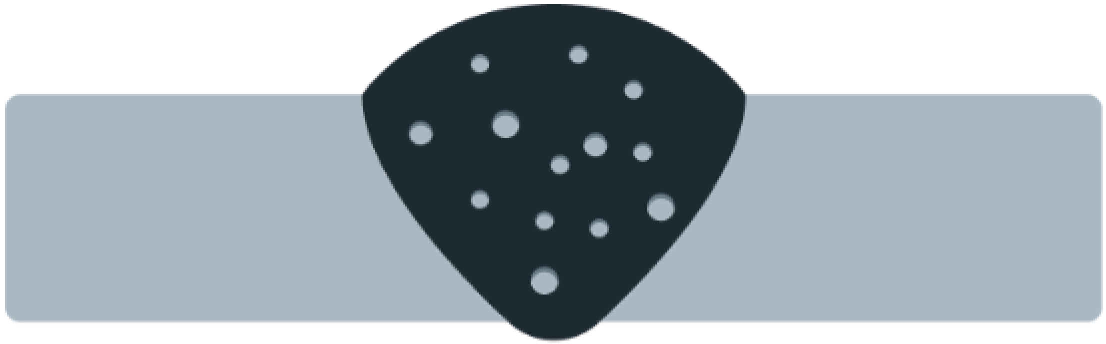
Causes

1.Using hydrogen shielding gas in welding ferrous metals.
2.Ductile base metal and the application of residual stress.
3.Rigid joints that constrain the expansion and contraction of the metal.
4.Use of high levels of sulphur and carbon.

Prevention

1.Preheating the metals and gradually cooling the weld joints.
2.Maintaining acceptable weld joint gaps.
3.Selection of the correct welding materials.

Porosity



Causes

1.Unclean welding surface.
2.Wrong electrode selection.
3.Lack or absence of shielding gas.
4.Mishandled or damaged shielding gas cylinder.
5.Either too low or too high welding current.
6.Fast travel speed.

Prevention

1.Cleaning the weld surface.
2.Using the correct welding electrode.
3.Preheating the metals before welding.
4.Proper gas flow rate setting to achieve the right amount of shielding.
5.Regularly checking for moisture contamination in the shielding gas cylinder.
6.Adjustment of welding current and travel speed settings.

Undercut

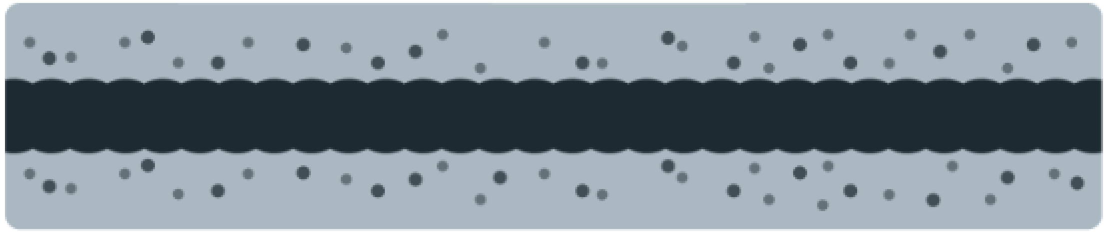
Causes

1. High arc voltage.
2. Incorrect electrode selection or wrong electrode angle.
3. High travel speed.

Prevention

1. Smaller arc length, voltage, and travel speed.
2. 30 to 45-degree electrode angle.
3. Reducing the electrode diameter.

Spatter



Causes

1.High arc length.
2.High welding current.
3.Improper shielding of the heat-affected zone.
4.Using the wrong polarity may create excessive spatter.

Prevention

1.Choosing the correct weld polarity.
2.Selecting a better shielding gas and better shielding technique.
3.Reducing the welding current and arc length to optimal condition.

Internal Welding Defects

Slag Inclusion

Causes

1.Incorrect welding angle and travel speed of the welding torch.
2.Poor pre-cleaning of the edge of the weld surface.
3.Low welding current density resulting in inadequate heating of the metals.

Prevention

1.Higher welding current density.
2.Optimal welding angle and travel speed to avoid slag inclusion in the weld pool.
3.Consistent weld edge cleaning and slag removal of each layer.

Incomplete Fusion

Causes

1.Low heat input resulting in metals not melting.
2.Wrong joint angle, torch angle, and bead position.
3.Extremely large weld pool.

Prevention

1.Higher welding current and slower travel rate to ensure the melting process of the metals.
2.Improving welding positions such as joint angle, torch angle, and bead position.
3.Lower deposition rate.

Incomplete Penetration

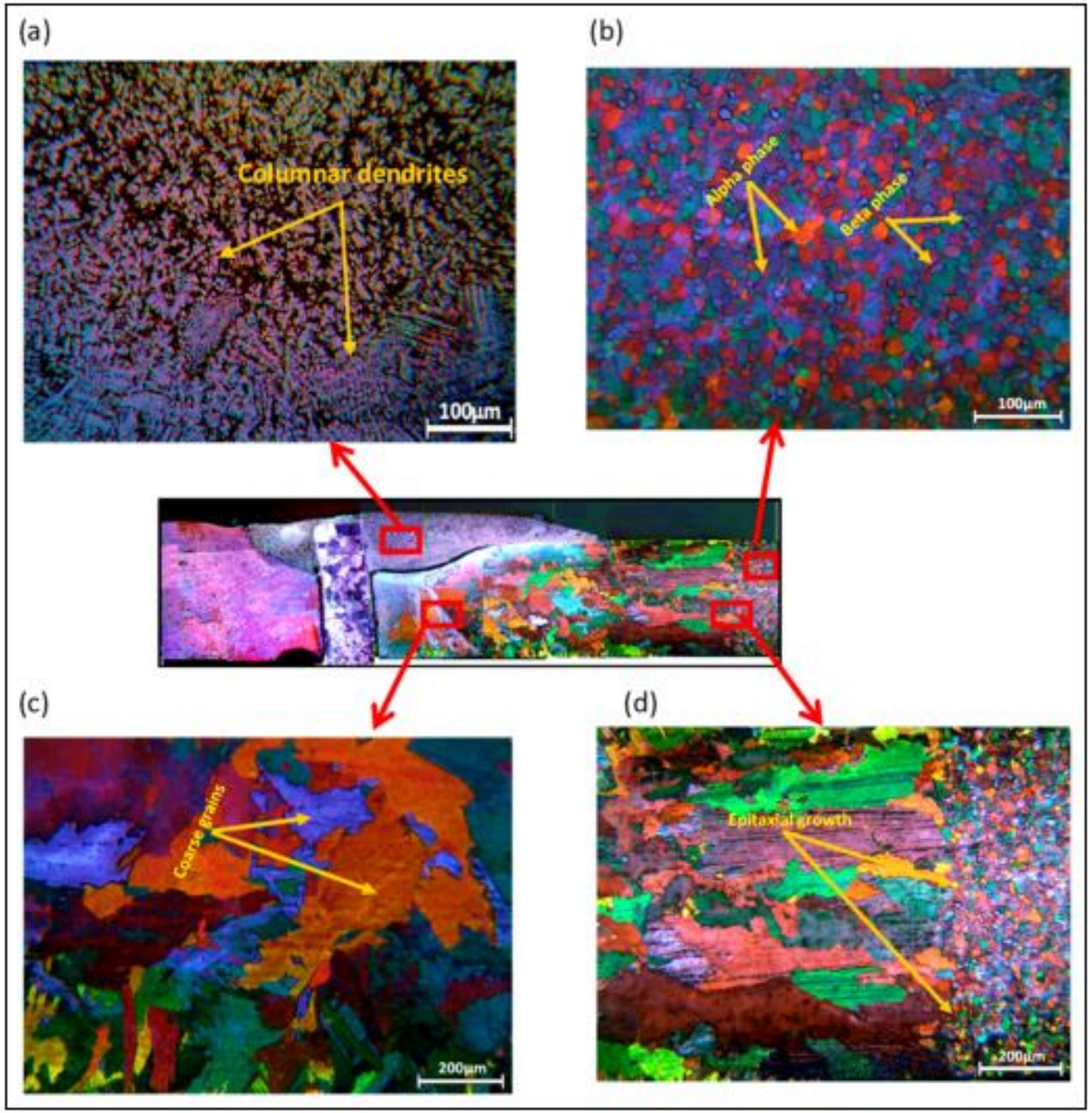
Causes

1.Incorrect use of the welding technique.
2.Wrong electrode size.
3.Low deposition rate.

Prevention

1.Using the correct welding technique and procedure.
2.Higher deposition rate.
3.Proper electrode size selection.

Weld Metal Nucleation Mechanisms

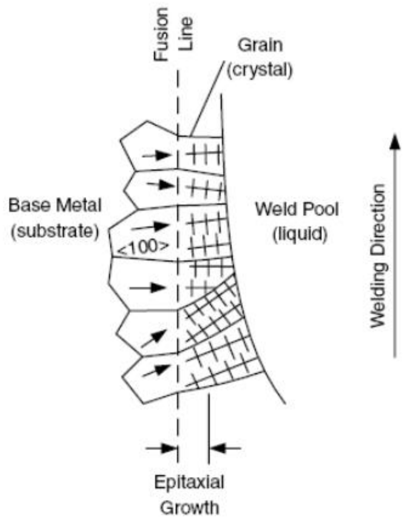


Epitaxial growth

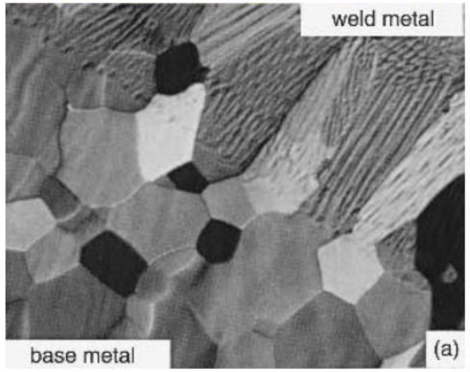
Epitaxial growth in welding occurs when the weld metal solidifies on a base metal, maintaining the crystallographic orientation of the substrate. Epitaxial growth is crucial in welding because it helps in reducing the number of grain boundaries, leading to better mechanical properties and corrosion resistance in the welded joint.

Mechanism: When the molten weld pool solidifies, the existing crystal structure of the base metal acts as a template. Atoms from the molten metal align themselves according to the crystallographic orientation of the substrate, leading to the continuation of the parent metal's grain structure into the weld.

Factors Influencing Epitaxial Growth: The temperature gradient, cooling rate, and chemical composition of the base and filler metals play significant roles. A high-temperature gradient and rapid cooling rate favor epitaxial growth by reducing the time available for new nucleation and allowing the existing crystals to grow.



Epitaxial growth of weld metal near fusion line



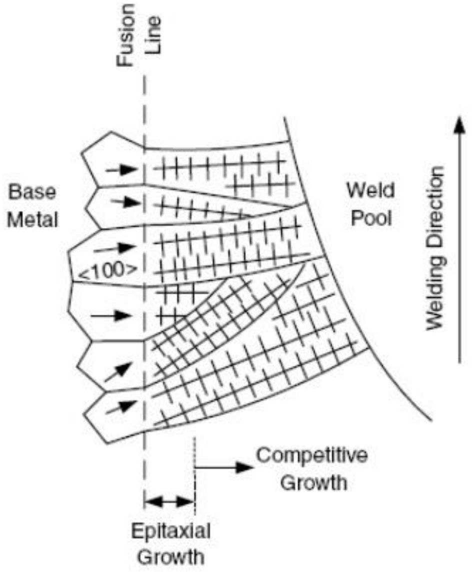
Epitaxial growth at fusion boundary

Competitive growth

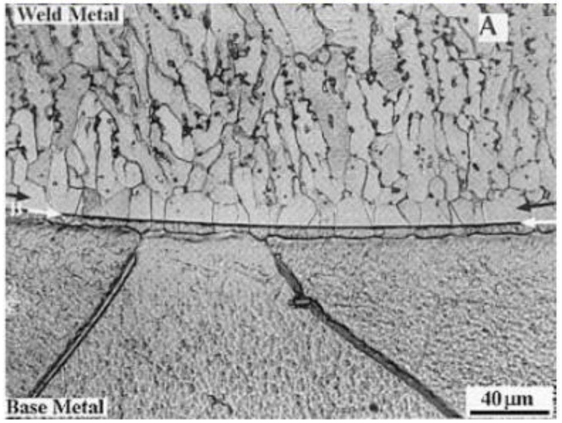
Competitive growth occurs when multiple grains nucleate and grow simultaneously in the weld pool, competing for space. This results in a mix of grain orientations and sizes, influencing the overall properties of the weld.

Mechanism: As the molten metal cools, different grains with various orientations begin to grow from the fusion line into the weld pool. The grains that are favorably oriented with respect to the heat flow direction grow faster and tend to dominate, outgrowing the less favorably oriented grains.

Factors Influencing Competitive Growth: The thermal gradient, cooling rate, and welding parameters such as heat input and travel speed affect competitive growth. Lower thermal gradients and slower cooling rates increase the chances of competitive growth by allowing more time for multiple nucleation events.



Competitive growth in bulk fusion zone.



Non-epitaxial growth at fusion boundary

Weld Metal Nucleation Mechanisms

Dendritic Fragmentation

- Weld pool convection can cause fragmentation in the mushy zone which act as a heterogeneous nucleation site.

Mechanism: During solidification, dendrites (tree-like structures) form in the molten metal. Under certain conditions, such as thermal fluctuations or fluid flow, these dendritic arms can fragment. These fragments, being solid, can serve as new nucleation sites and grow into new grains.

Grain Detachment

- Weld pool convection can cause detachment of grains in the mushy zone which act as a heterogeneous nuclei.

Mechanism: Grains that nucleate at the solid-liquid interface can be detached by fluid flow or thermal stresses. These detached grains then move into the weld pool and act as nucleation sites for new grains.

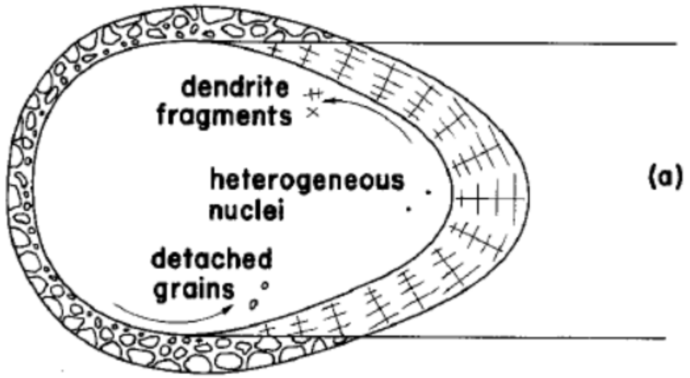
Heterogeneous Nucleation

- Foreign particles present in the weld pool upon which atoms in the liquid metal can be arranged in a crystalline form can act as heterogeneous nuclei.

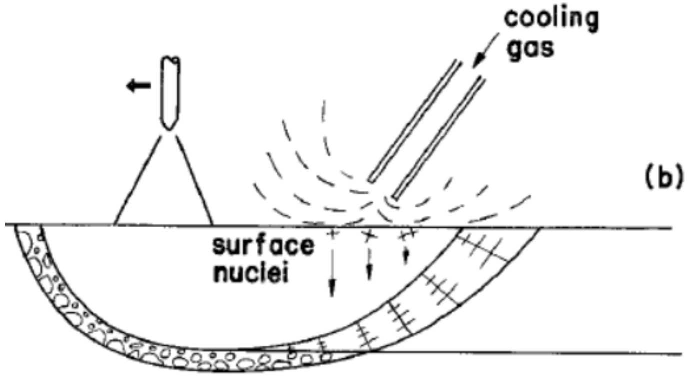
Mechanism: Foreign particles or inclusions in the molten metal provide sites for nucleation by reducing the energy barrier required for the formation of stable nuclei. These sites can be oxides, carbides, or other non-metallic inclusions.

Surface Nucleation

Mechanism: The weld pool surface can be undercooled thermally to induce surface nucleation by exposure to a stream of cooling gas or by instantaneous reduction or removal of the heat input.



MECHANISM 1: Dendrite Fragmentation
MECHANISM 2: Grain Detachment
MECHANISM 3: Heterogeneous Nucleation



MECHANISM 4: Surface Nucleation

Solidification of melt zone